DEVELOPMENT OF A DC-AC POWER CONDITIONER FOR WIND GENERATOR BY USING FUZZY LOGIC

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ABSTRACT

In this project, a fuzzy logic controller is designed to obtain the desired output voltage of DC-AC power conditioner used in a stand alone wind generator which the Fuzzy Logic Controller (FLC) is employed to control the modulation index of the SPWM (Sinusoidal -Pulse Width-Modulation) inverter which is built using four MOSFET's transistor. This project present of development single phase DC-AC converter for wind generator application. The mathematical model of the wind generator and Fuzzy Logic Controller for DC-AC converter is derived. The controller is designed to stabilize the output voltage of DC-AC converter. To verify the effectiveness of the proposal controller, both simulation and experimental are developed. The simulation and experimental result show that the amplitude of output voltage of the DC-AC converter can be controlled.

ABSTRAK

Projek ini mempersembahkan fasa tunggal pembangunan penukar DC-AC untuk aplikasi penjana angin. Model matematik penjana angin dan kawalan Fuzzy Logic Controller untuk penukar DC-AC diterbitkan. Pengawal direka bagi memantapkan voltan keluaran penukar DC-AC. Untuk mengesahkan keberkesanan pengawal cadangan, kedua-dua simulasi dan eksperimen telah dibangunkan. Simulasi dan keputusan eksperimen menunjukkan bahawa amplitud voltan keluaran penukar DC-AC boleh dikawal.

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LIST OF ABBREVIATIONS AND ACRONYMS

DC	-	Direct Current
AC	-	Alternate Current
SPWM	-	Sinusoidal Pulse Width Modulation
MATLAB	-	Matrix Laboratory
DSP	-	Digital signal Processes
FLC	-	Fuzzy Logic Controller
SIMULINK	-	Simulation and Link
IGPT	-	Insulated Gate Bipolar Transistor
MOSFET	-	Metal Oxide Semiconductor Field-Effect Transistor
VDC	-	Voltage Direct Current
Vr	-	Voltage Reference
Vo	-	Voltage output
Vc	-	Voltage Carrier
Mi	-	Modulation Index
PCB	-	Printed Circuit Board
E	-	Error
DE	-	Delta Error
MF	-	Member Function
WECS	-	Wind Energy Conversion Systems

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, a large interest to power the world with clean energy has become a world target. This has motivated all researchers to redirect their work into the renewable energy source. Wind turbine is considered as one of the targeted clean energy source. Wind turbines are electromechanical devices that convert the wind energy into electrical energy. The wind turbine is mix and match a variety of innovation concepts with proven technologies both generators and power electronics (Thomas Ackermann, 2005).

There are several types of design of wind turbines generators; which is either AC or DC generators, such as “AC generators (induction- asynchronous) and DC generators (shunt wound-series wound)”.Output of wind generator depends on wind speed therefore to maintain the output voltage a power conditioning is required (Thomas Ackermann, 2005).

The power conditioners must have the following specifications:

- High gain, to contribute to energy conservation in the form of various products, ranging from a lot of appliances.
- Small current ripple.
- High efficiency and low cost (Hongzhong Ma et al.; 2009).

The DC-AC power conditioners are equipments that generate wind power by converting direct current, supplied by generator of wind turbine, into alternating current. In this power conditioner, the electric energy, generated by DC generator which is driven by the wind turbine, changes into qualified AC energy by DC-AC inverter. An inverter (DC-AC with controllable frequency and voltage) to covert direct current into alternating current, while the energy flows to the AC side (Hongzhong Ma et al.; 2009).At the same time, the storage battery, mounted between the output of the DC generator and the SPWM inverter, can compensate the voltage variation caused by variable wind speed by charge-discharge in a small range to keep the output power constant

The pulse width- modulated (PWM) DC-AC inverter has been the main choice in power electronics for deadest, because of its circuit simplicity and rugged control scheme. Modulation techniques are used in inverter to regulate output voltage/current by using IGBT inverter. The pulse width modulation technique decides the switching losses in the inverter, harmonic contents in output waveform, and overall performance of the inverter. Sine wave pulse width modulation (SPWM) is most widely used scheme due to its simplicity and better output profile (Maria D. Bellar,1998).

In consideration of the characteristics of wind power system and DC generator, a wind power generation in this system based on DC generator with DC-AC power conditioner are developed, which consists of a variable pitch wind turbine, an adjustable excitation DC generator, which a SPWM inverter with low-frequency parts and some other related control parts. The main task of wind turbine control system is enabling continuous power production under all operating conditions determined by various wind speeds (Thomas Ackermann, 2005).

As output power is directly proportional to generator speed, power control can be done by controlling generator speed or by controlling inverter SPWM by using fuzzy logic controller as an alternative approach to wind turbine modeling is proposed in this system.

1.2 Objective of Project.

- Develop simulation model of DC-AC power conditioner for wind generator
- Using MATLAB of Fuzzy Logic controller for DC-AC power conditioner
- Develop single phase DC-AC power conditioner using Mosfet semiconductor.

1.3 Problem Statement.

Due to the volatility and the uncontrollability of wind source, hence output power of a wind generator become unstable. By this reason a variable speed wind energy systems integrated with power electronic interfaces are becoming popular because it can extract maximum power from the wind and maintain constant output. In this project the problem statements are how to develop simulation model of inverter, sinusoidal PWM and Fuzzy Logic Controller (FLC).also how to develop single phase inverter circuit wiring Mosfet and SPWM program in DSP board

1.4 Scope of Project.

This project is primarily concerned with development of (DC-AC) power conditioner for wind generator. The scopes of this project are:-

- Modeling of a DC wind generator, DC-AC converter and Fuzzy Logic Controller are simulating using MATLAB.
- Sinusoidal Pulse Width Modulation (SPWM) technique is used to control the switching signals for the DC-AC power inverter
- Using neural Fuzzy Logic technique as controller to improve performance of power conditioner for system
- The controller and (SPWM) develop in DSP Board

CHAPTER 2

LITERATURE REVIEW ON WIND TURBINE

2.1 Electrical Characteristics of a variable –speed wind turbine

Variable–speed turbines are designed to achieve maximum aerodynamic efficiency over a wide range of wind speeds. With variable –speed operation it has become possible continuously to adapt (accelerate or decelerate) the rotational speed ω of the wind turbine to the wind speed υ. This way, the tip speed ratio γ is kept constant at a predefined value that corresponds to the maximum power coefficient the relationship between a variable – speed wind turbine generator and output power is described in figure 2.1(Thomas Ackermann,2005).

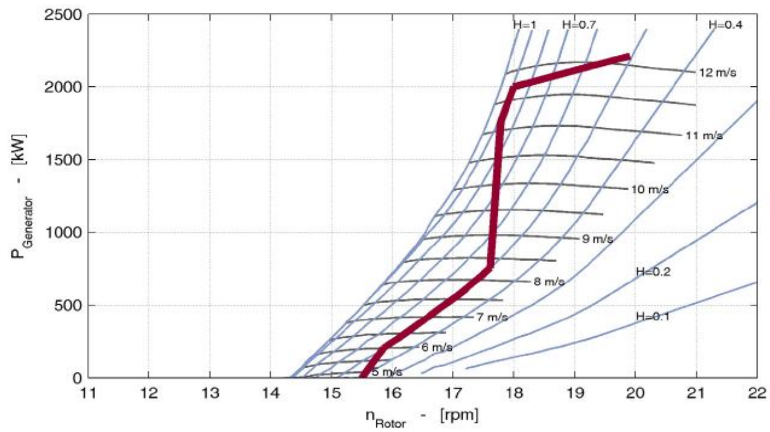

Figure 2.1: Showing electric power as a function of rotor speed with curves and curves of same wind speed.

The advantages of variable-speed wind turbines are an increased energy capture, improve power quality and reduced mechanical stress on the wind turbine. The introduction of a variable –speed turbine types increases the number of applicable generators types and also introduces several degrees of freedom in the combination of generator type and power converter type (Mukund R. Patel, 2006).

The advantages of variable-speed direct-drive wind turbine system include increased energy capture , reduce cost and improved reliability through elimination of the mechanical gearbox ,and reduction of mechanical stresses throughout the turbine, also, the key to economically viable direct-drive variable-speed wind turbine is the selection and design of the generator such as DC generator (David A-Torrey et al.;2001).

2.1.1 Wind turbine with gearbox

The principle of a design of a wind turbine with gearbox is shown in figure 2.2.The main aspect of this design is the split shaft system, where the main shaft turns slowly with the rotor blades and torque is transmitted through a gearbox to the high –speed secondary shaft that drives the few-pole pair generator. The transmission of torque to the generator is shut off by means of a large disk brake on the main shaft. A mechanical system controls the pitch of the blades, so pitch control can also be used to stop the operation of the converter, in stormy conditions. The pitch mechanism is driven by a hydraulic system, with oil as the popular medium. For construction without a main brake, each blade has its pitch angle controller by a small electric motor. The gearbox concept was in many cases accompanied by an insufficient life time because of failure of gearbox (Hermann-Josef wanger et al.; 2010).

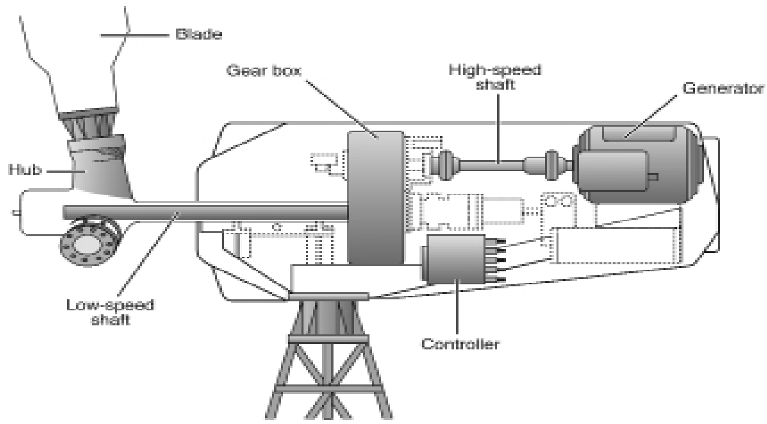

Figure: 2.2: wind turbine with gearbox (wind system, 2010)

2.1.2 Wind turbine without gearbox

The main idea for this design depends on another converter type without gearbox is shown in Fig 2.3. This design has adjusted one stationary shaft .The rotor blades and the generator is both mounted on this shaft. The multi-pole generator is in the form of a large spoked wheel with. Forty-tow pole pairs around the outer circumference and stators mounted on a stationary arm around the wheel. The wheel is fixed to the blade apparatus, so it rotates slowly with the blades. Therefore, there is no need for a gearbox, rotating shafts or a disk brake. This minimizing of rotating parts reduces maintenance and failure possibilities and simplifies the maintenance and production of the converter. The price for these advantages is a high nacelle mass caused by the high copper content of multi-pole generator (Hermann-Josef wanger et al.; 2010).

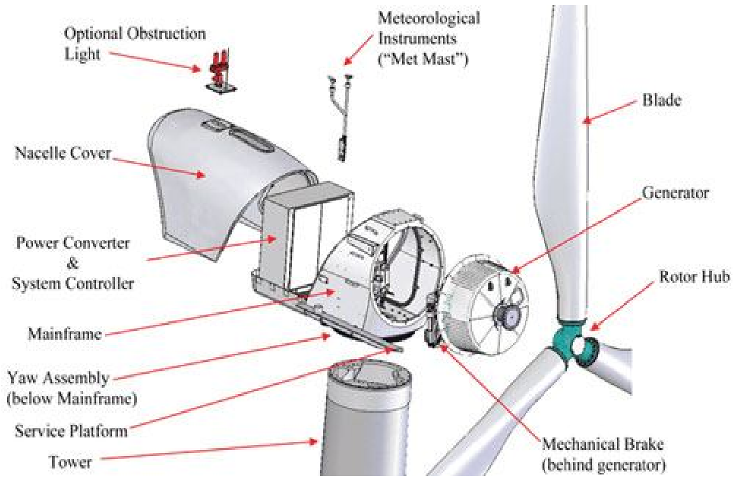

Figure 2.3: wind turbine without gearbox (wind system, 2010)

2.2 DC generator for the wind turbine

The DC generator converts the inside AC into DC for outside use. It does so by using a mechanical commutator. It switches the positive output terminal continuously to the conductor generating the positive polarity voltage, and likewise for the negative polarity terminal which the sliding contacts inherently result in low reliability (Muhammad H.Rashid, 2006). Despite this disadvantage, the DC generator use in a limited numbers of wind power installation of a small capacity. Figure 2.4 shows the curves of the relationship between the required field current and the rotation speed of the variable wind turbine.

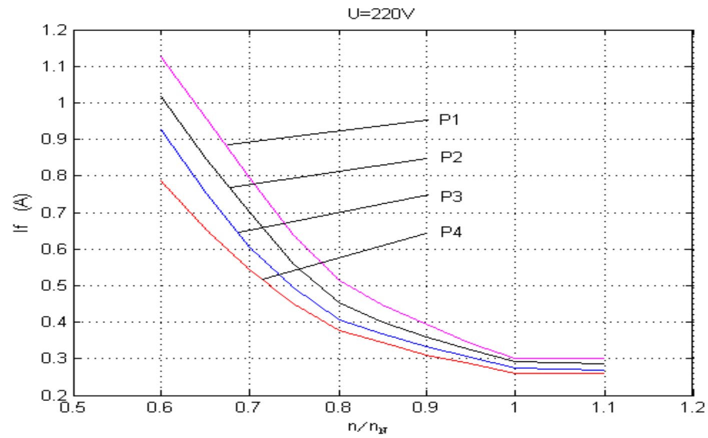

Figure 2.4: Influence on the field current for variable wind speed (P1>P2>P3>P4).

Because of the directly driving technique, there is no need to mount the gearbox between the wind turbine generator and the DC generator, so that the operating efficiency is greatly improved, the running noise is moderated and the maintenance work is reduced. Because of DC output of the generator here only needs to DC-AC inversion and the generator can be connected to grid through the step up transformer. Compared with the AC-DC-AC part of the traditional AC generator, the AC-DC part is not needed so that the equipment investment is reduced and the operational reliability is improved (Hongzhong Ma et al.; 2009).

2.3 Characteristics of a small wind-power system with DC generator

The performance characteristics of a small-scale wind-power system with a separately or self-excited DC generators are appears in the following points

- Relatively cheap electronics
- Good damping and stability
- Easy synchronization to grid

- With the converter as rectifier, the dc .machine may be run as a motor (useful for starting vertical axis machines).
- Electronics limit the fault level. (L.L.Freris, 1990).
- That the maximum output is proportional to the cube of the wind speed and consequently the field current (or the load resistance) must be controlled over a wide wind speed range to obtain maximum output power (T. Suzuki et al.; 1982).

2.4 power control using speed variation

1. When the frequency is constant, the speed of a wind turbine can be influenced as allows:

    - Mechanically by varying the transmission ratio if the generator speed is constant.
    - Electronically by frequency converter if the speed is rotation is variable over the entire drive train (turbine, gearing, and generator).

    The turbine speed can thus be adapted to meet operational requirements. Varying the rotor speed in turn varies the power of the turbine, allowing it

    - To be brought into the maximum range, depending on available wind, or
    - To be reduced if required meeting user requirements.

    Currently used power electronics (rectifiers, commutated inverters) to convert the frequency to that required (Siegfried Heier,2006).

2. When there is flexible coupling for grid or equipments are employed, the effect Fluctuations in available wind can be reduced by making use of the rotating Mass of the drive train to:
    - smooth out variations in rotor speed and reduce the dynamic load on the entire system.

In this way, the power converter allows a very Short- time intervention at the generator, which allows the requirements and desired to be achieved at the turbine via the drive train (Siegfried Heier, 2006).

2.5 Modern power electronics in wind turbine systems

The wind turbine behavior/performance is very much improved by using power electronics. They are able to act as a contributor to the frequency and voltage control. Also it can be concluded the power scaling of wind turbines is important in order to be able to reduce the energy cost.

Power electronics has changed rapidly during the last thirty years and the number of applications has been increasing, mainly due to the developments of the semiconductor devices and the microprocessor technology. For both cases higher performance is steadily given for the same area of silicon, and at the same time they are continuously reducing the price. Figure 2.5 shows a typical power electronic system consisting of a power converter, a load/source and a control unit as in wind turbine system (F. Blaabjerg, 2006).

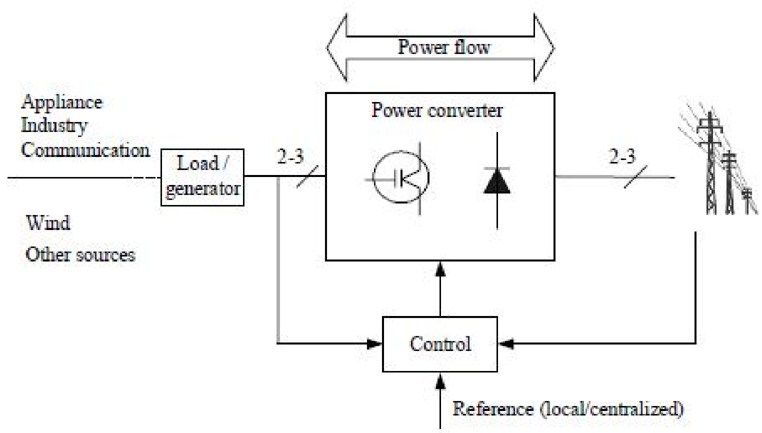

Figure 2.5: power electronic system with the grid, load/source, power converter and control. (F. Blaabjerg, 2006).

The power converter is the interface between the load/generator and the grid. The power may flow in both directions, of course, dependent on topology and applications. Three important issues are of concern using such a system. The first one is reliability; the second is efficiency and the third one is cost. For the moment the cost of power semiconductor devices is decreasing 2-5 % every year for the same output performance and the price pr. kW for a power electronic system is also decreasing. The key driver of this development is that the power electronic device technology is still undergoing important progress. Figure 2.6 shows different key power devices and the areas where the development is still going on.

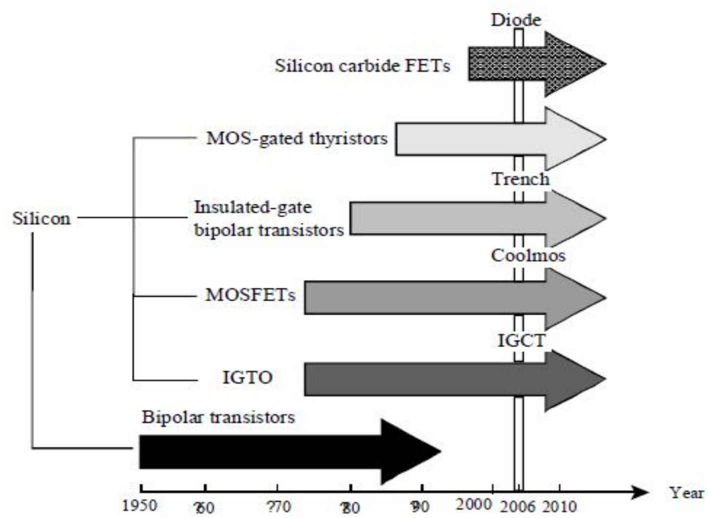

Figure 2.6: developments of power semiconductor devices in the past and in the future which are used in wind energy technology (F. Blaabjerg, 2006).

The only power device which is not under development any more is the silicon-based power bipolar transistor because MOS-gated devices are preferable in the sense of easy control. The breakdown voltage and/or current carrying capability of the components are also continuously increasing. Also important research is going on to change the material from silicon to silicon carbide. This may dramatically increase the power density of power converters but silicon carbide based transistors on a commercial basis with a competitive price will still take some years to appear on the market(F. Blaabjerg, 2006).

2.6 power conditioning

Power conditioning, as well as energy conversion, represented a decisive milestone in the development of wind energy technology. In the 1980s, only high-output pilot energy were constructed and operated as variable-speed units. Development progressed from the cheap six-pulse converters with thyristors through quasi-twelve-pulse circuits to the called pulse-controlled converters with semiconductors switches operating in the kilohertz range.
This type of system also requires a converter system that is capable of conditioning the variable-frequency electrical energy from the wind turbine generator for supply to a lot of equipments of constant frequency and voltage (T. Suzuki et al.; 1982).

2.7 Pulse –width- modulation inverter

DC-AC converters are known as inverter. The function of an inverter is to change a dc input voltage to a symmetric ac output voltage of desired magnitude and frequency. It has a following Characteristic:

- The output voltage could be fixed or variable at a fixed or variable frequency.
- A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant.
- If the dc input voltage is fixed and it isn't controllable, a variable output voltage can be obtained by varying the gain of the inverter.
- The control of output voltage is normally accomplished by (PWM) control within inverter.
- The waveforms of practical inverters are no sinusoidal and contain harmonics.
- Each type of inverter can use controlled turn-on and turn-off devices such as: metal oxide semiconductor field-effect transistors [MOSFETs], and insulated-gate bipolar transistor [IGBTs] (Muhammad H.Rashid 2006).

2.8 Fuzzy Controller

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system.

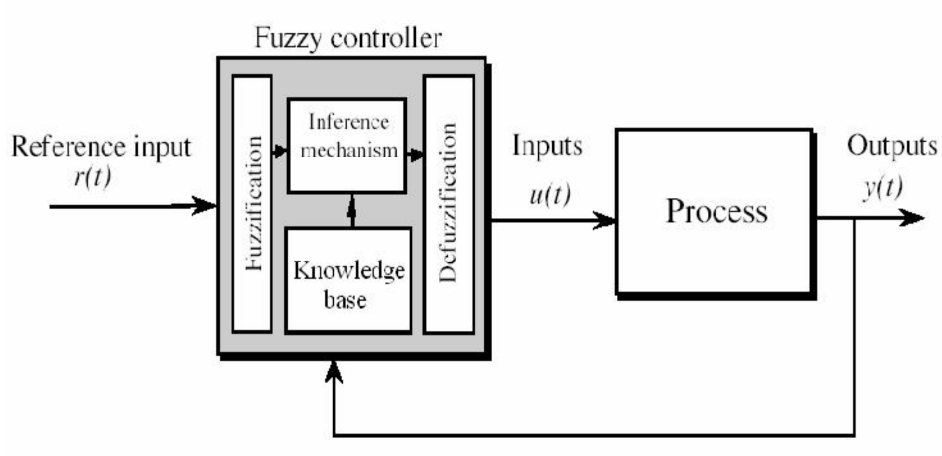

Figure 2.7: diagram of fuzzy controller

2.8.1 Useful cases

- The control processes are too complex to analyze by conventional quantitative techniques.
- The available sources of information are interpreted qualitatively, inexactly, or uncertainly (P. Siarry & F. Guely, 1998).

2.8.2 Advantages of FLC

- Parallel or distributed control multiple fuzzy rules – complex nonlinear system
- Linguistic control. Linguistic terms - human knowledge
- Robust control. More than 1 control rules – an error of a rule is not fatal (P. Siarry & F. Guely, 1998).

2.9 construction of fuzzy controller

Most commercial fuzzy products are rule-based systems that receive current information in the feedback loop from the device as it operates and control the operation of a mechanical or other device (P. Siarry & F. Guely, 1998). A fuzzy logic system has four blocks. Crisp input information from the device is converted into fuzzy values for each input fuzzy set with the fuzzification block. The universe of discourse of the input variables determines the required scaling for correct per-unit operation. The scaling is very important because the fuzzy system can be retrofitted with other devices or ranges of operation by just changing the scaling of the input and output. The decision-making-logic determines how the fuzzy logic operations are performed (Sup-Min inference), and together with the knowledge base determine the outputs of each fuzzy IF-THEN rules. Those are combined and converted to crispy values with the defuzzification block. The output crisp value can be calculated by the center of gravity or the weighted average. Figure 2.8 Fuzzy Controller Block Diagram.

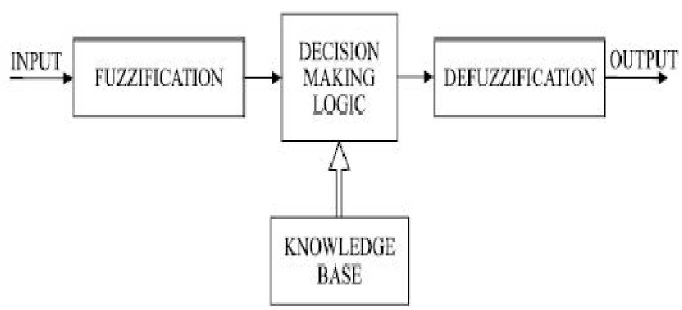

Figure 2.8: Fuzzy controller block diagram (P. Siarry & F. Guely, 1998).

2.10 Gaussian Membership Functions

Fuzzy membership function as shown in figure 2.9 that is of- ten used to represent vague, linguistic terms is the Gaussian which is given by:

$$\mu_{A^i}(x) = \exp(-\frac{(c_i - x)^2}{\sigma_i})$$

Where ci and _i are the centre and width of the ith fuzzy set Ai, respectively.

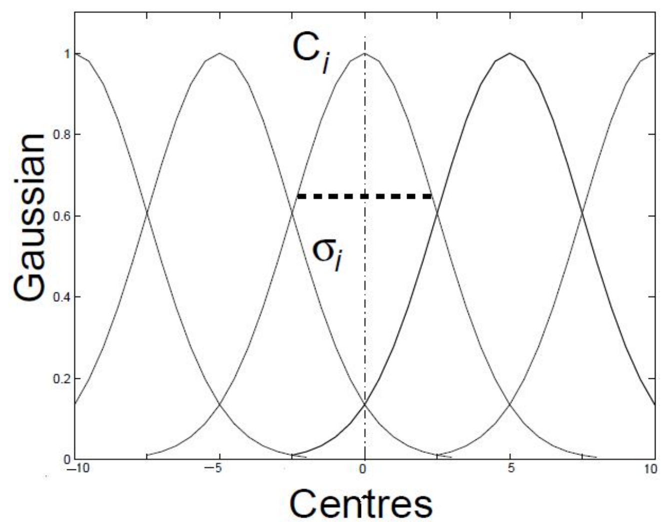

Figure 2.9 :Gaussian Membership Functions (personal.rdg.ac.uk)

2.10.1 Characteristics of Gaussian method

- Local although not strictly compact
- The output is very smooth
- Not probability
- Multivariate Gaussian functions can be formed from the product of the univariate sets.

- Gaussian fuzzy membership functions are quite popular in the fuzzy logic literature, as they are the basis for the connection between fuzzy systems and radial basis function (RBF) neural networks (personal.rdg.ac.uk).

2.11 Real-time F2808 eZdsp

Real-Time Workshop generates and executes stand-alone C code for developing and testing algorithms modeled in Simulink and Embedded MATLAB™ code. The resulting code can be used for many real-time and non-real-time applications, including simulation acceleration, rapid prototyping, and hardware-in-the-loop testing. Through real-time technology can tune and monitor the generated code using Simulink blocks and built-in analysis capabilities, or run and interact with the code outside the MATLAB and Simulink environment.
Options on the block mask allow setting features of code generation for Spectrum Digital F2808 eZdsp target. Adding this block to Simulink model provides access to building, linking, compiling, and targeting settings it needs to configure the code that Real-Time Workshop generates (mathworks, 2011).

2.12 DSP TMS 320F 2808 board

The TMS2808 DSP Controller Board is designed around the fast state-of-the-art digital signal processor (DSP) TMS320F2808 from Texas Instruments. This DSP is designed using high-performance static CMOS technology allowing operation at 100 MHz in the temperature range from -40C to 125C. This DSP has a 32-bit high performance CPU allowing 16 X 16, 32 X 32 MAC operations as well as 16 X 16 dual MAC operations. It has HARVARD bus architecture with atomic operation, fast interrupt response and processing and a unified memory programming model. The DSP chip has a watchdog timer module, a powerful peripheral interrupt expansion (PIE) block that supports all 43 peripheral interrupts. It also has a 128-Bit security key/lock which protects Flash/OTP/L0/L1 memory blocks and prevents firmware reverse engineering. This board was designed in order to offer a powerful solution for a wide variety of power conversion or power electronic applications such as motor drives (induction motor, brushless, DC or AC), power factor correction, active filters, single or three phase inverters, converters (AC/DC, DC/AC, AC/AC,DC/DC), SCR controlled converters and others. Figure 2.10 shows F2808 DSP board (Texas Instruments, 2007)

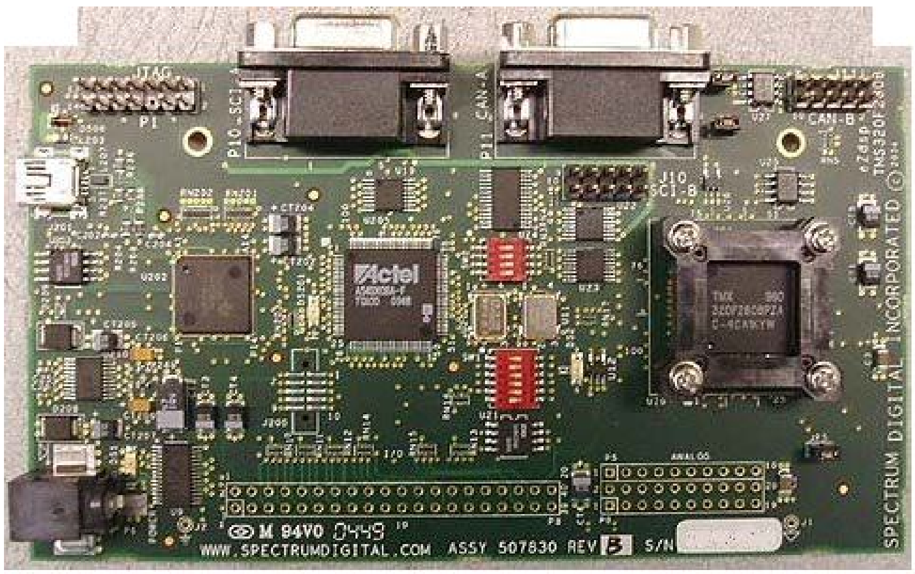

Figure 2.10: F2808 DSP board (Texas Instruments, 2007)

CHAPTER 3

METHODOLOGY

3.1 Research Design

To ensure access to electrical energy with a constant voltage is suitable for many purposes that their source is variable speed wind energy, this is done using single-phase inverter DC-AC controlled by the Fuzzy logic controller, without the use of control the speed of turbine generator. The work is beginning with the discussion of project title, objective and scope followed by seeking the information for literature review and the time schedule arrangement. Literature review in the previous chapter presents the characteristics of all system of wind turbine using as standalone generator, and it shows importance using the power electronics in application of wind turbine, also it explained using the fuzzy logic controller to control the output of wind turbine instead of gearbox which is the fuzzy logic controller widely used for process control in industries. This project presents a rule-based fuzzy logic controller to control the output power of a sinusoidal pulse width modulated (SPWM) inverter used in standalone wind energy. The Obtained experimental and simulation results show the effectiveness of the proposed fuzzy logic controller. The implementation of this project is based on the approach to design and develop a (SPWM) DC-AC inverter and FLC for output voltage control. The design details of the terms which are related to the fuzzy logic controller are discussed in this section. Figure 3.1 shows the overview of the methodology flow chart of this project.

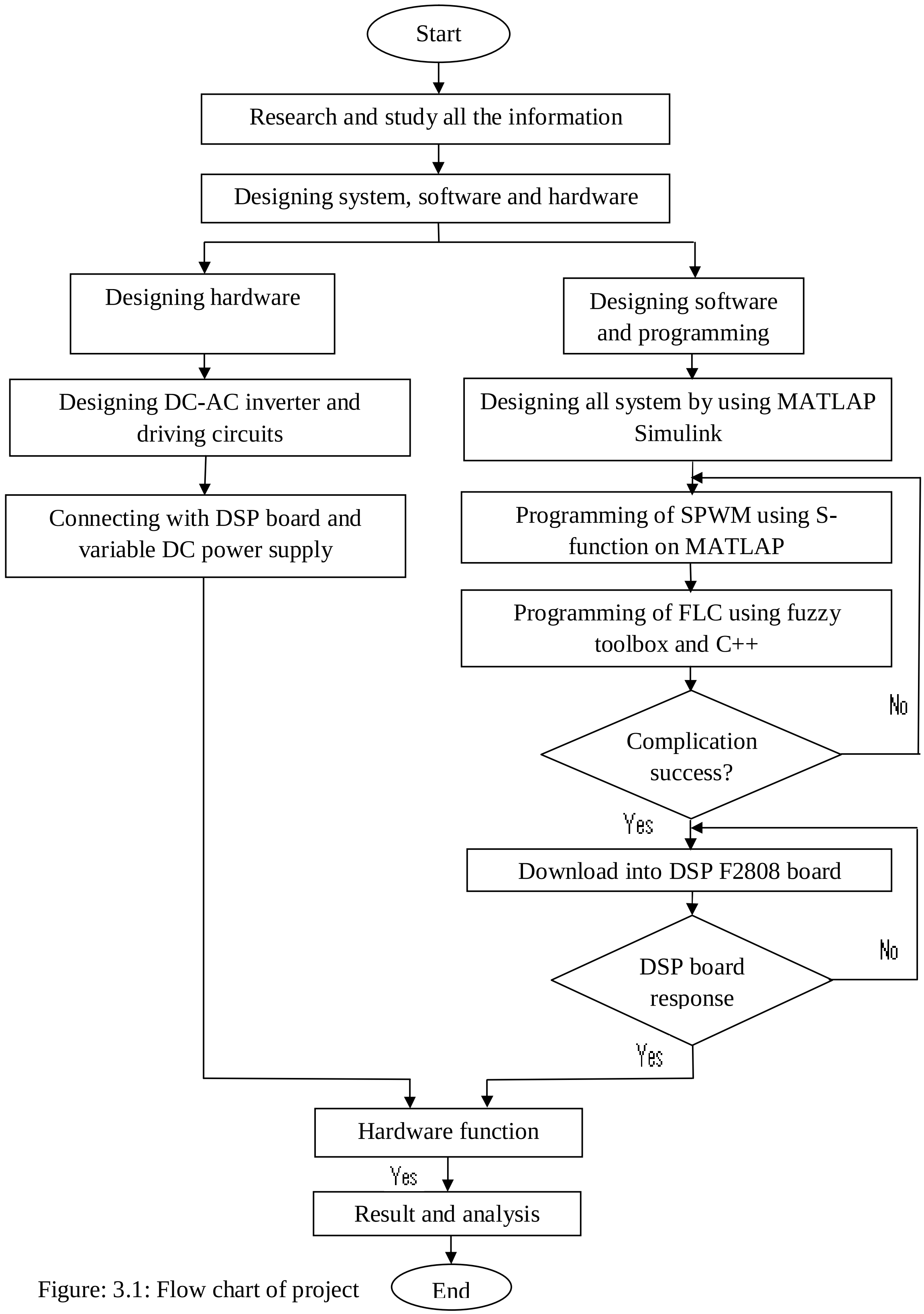

Figure: 3.1: Flow chart of project

3.1.1 System Description

Figure (3.2) describes a synoptic scheme of the wind turbine system, used in this project. It includes a DC generator wind turbine (variable DC power supply), which the output of generator connected to (SPWM) DC- AC inverter that connected to controller (fuzzy logic controller) for adjustment the output of inverter by comparing the actual output voltage of inverter with reference voltage of input.

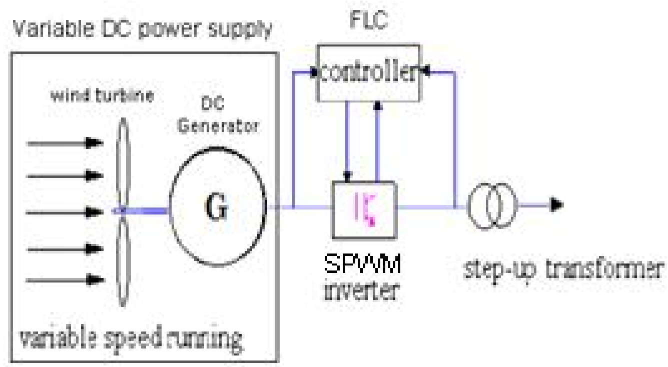

Figure 3.2: Synoptic system of wind turbine

3.1.2 Single phase bridge inverter

A single-phase bridge voltage source inverter (VSI), it consists of four choppers as shown in figure 3.3, when transistor Q1 and Q2 are turned on, the input voltage Vs appears across the load. If transistors Q3, Q4 are turned on at the same time, the voltage across the load is reversed and is –Vs. The wave forms for the output are shown in figure 3.4. The rms output voltage can be found from the following equation (3.1)

$$V_o = \left(\frac{2}{T_0} \int_0^{T_0/2} V_s^2 \, dt \right)^{1/2} = V_s \qquad (3.1)$$

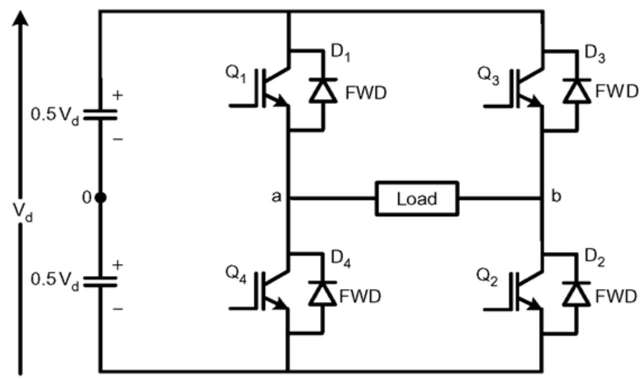

Figure 3.3: Single-phase full-bridge inverter

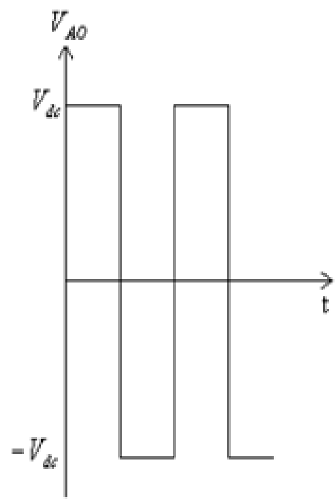

Figure 3.4: waveform for the inverter output

3.1.2.1 Inverter circuit using Matlab Simulink

Single phase full bridge inverter only consists of four arrangements of power switches .Transistor MOSFIT 530N is used as a power switch in this project. The DC input voltage is set to 400 volt dc for the entire inverter (refers APPENDEIX A). The four output signals form SPWM programming block is directly connected to MOSFIT's gate terminal. The process of inverter circuit is shown in flowchart 3.5

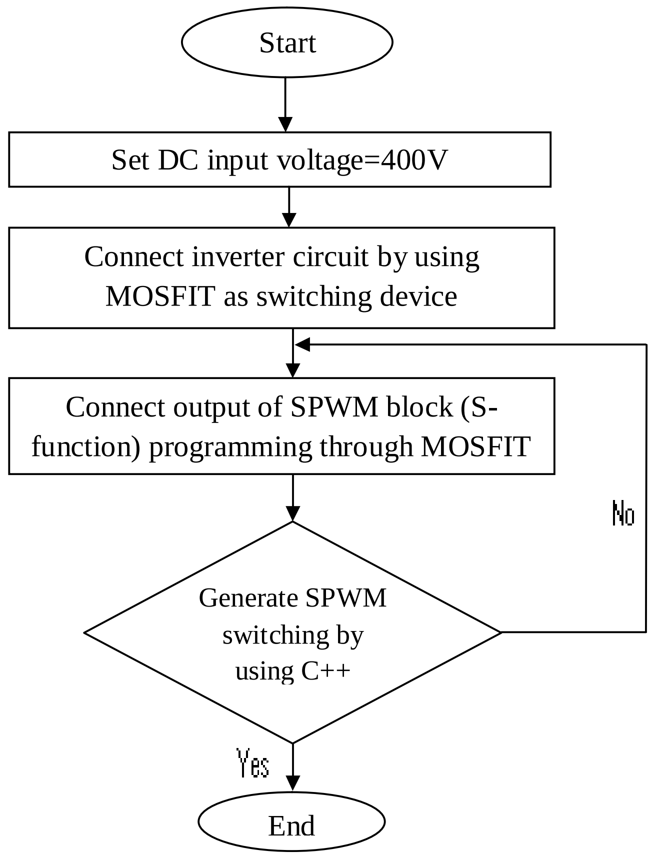

Figure 3.5:flowchart of processing inverter circuit using Matlab Simulink

3.1.3 Control Strategies of Sinusoidal PWM waveforms

In SPWM the output voltage signal can be obtained by comparing a control signal, *cont v*, against a sinusoidal reference signal, *ref v*, at the desired frequency is shown in Figure 3.6. At the first half of the output period, output voltage takes a positive value (+ dc V), whenever the reference signal is greater than the control signal. At the same way, at the second half of the output period, the output voltage takes a negative value (- dc V) whenever the reference signal is less than the control signal.

The control frequency *cont f* determines the number of pulses per half of cycle for the output voltage signal. Also, the output frequency *Of* is determined by the reference frequency *ref f*. The modulation index Ma is defined as the ratio between the sinusoidal magnitude and the control signal magnitude (Muhammad H.Rashid,2006).

To obtain a vary train of pulses, each pulse has to vary proportional to the necessary fundamental component precisely at the time when this pulse occurs. The frequency of the output waveform needs to be higher than the frequency of the fundamental component. By varying the width of each pulse, the inverter is able to produce different levels of output voltage for the corresponding pulse event.

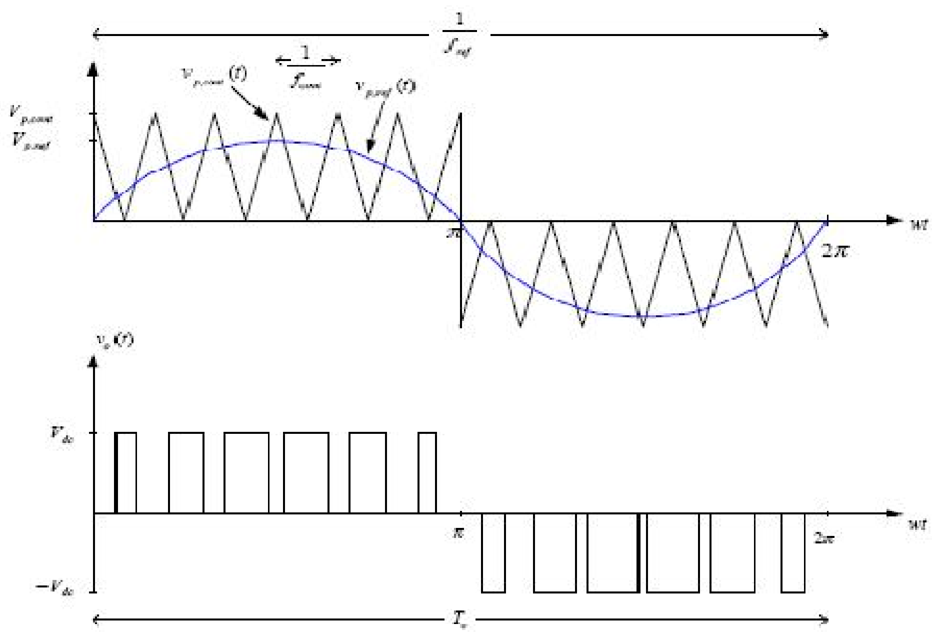

Figure 3.6: SPWM and inverter output voltage

3.1.3.1 SPWM generating using C++ programming by Matlab Simulink

The SPWM generator should be able to produce output frequency of 50 Hz and generate pulses of SPWM switching signal per complete cycle. The modulation

REFERENCES

[1] Thomas Ackermann " wind power in power systems " 2005.

[2] Hongzhong Ma, Lin Chen, Ping Ju, Haihua Liu, Ning Jiang and Chunning Wang, "Feasibility Research on DC Generator Based Wind Power Generation System" , *IEEE* international conference o. 6.7 April 2009.

[3] Maria D. Bellar, Student Member, IEEE, Tzong-Shiann Wu, Member, IEEE, Aristide Tchamdjou, Student Member, IEEE, Javad Mahdavi, Senior Member, IEEE, and M. Ehsani, Fellow, IEEE,"A Review of Soft-Switched DC–AC Converters". IEEE transaction on industry application, vol.34.no.4, July/august 1998.

[4] Mukund R. Patel"wind and solar power systems ", second edition, 2006.

[5] david A-Torrey , Sussan E-childs, Sjoerd de Hann "a variable-speed wind turbine based on a direct –drive avariable- reluctance generator",IEEE.

[6] Hermann-Josef wanger, Yotirmay mathur ."Introduction to wind energy systems(Basics,Technology and Operation). Second edition 2010.

[7] Muhammad H.Rashid" Power Electroics",*circuits*,*devices*,*adapplication*,third edition,2006.

[8] L.L.Freris "Wind energy conversion systems" 1990.

[9] T. Suzuki, Ph.D., H. Okitsu, Ph.D., and T. Kawahito" Characteristics of a small wind-power system with DC generator", IEEE PROC, Vol. 129, Pt. B, No. 4, JULY 1982.

[10] Siegfried Heier "Grid Integration of Wind Energy Conversion Systems", . second edition, 2006.

[11] F. Blaabjerg , Chen, R.Teodorescu ,F.lov "Power Electronics in wind turbine .

[12] P. Siarry, F. Guely, Fuzzy Sets Syst. 99 (1) (1998) 37–47.

[13] www.personal.rdg.ac.uk.

[14] www.mathworks.com.

[15] (Texas Instruments) www.focus.ti.com .

[16] (Wind systems) www. windsystemsmag.com.